NUMERICAL SIMULATIONS OF HYDRODYNAMICALLY INTERACTING GRANULAR PARTICLES

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In some of the systems of granular materials, the hydrodynamic effects of the fluid surrounding particles have an important role. Granular flows in a fluidized bed [1] and a narrow pipe [2] are studied numerically by the model taking account of hydrodynamic effects.

We assume that direct collisions between particles are elastic, the Brownian force is negligible and Stokes approximation is acceptable. In the simulation, we use the following model,

$$\tilde{St}\frac{d}{dt}\mathbf{U}^{(\alpha)} = -\mathbf{U}^{(\alpha)} + \mathbf{V}_t^{(\alpha)}, \tag{1}$$

$$-\mathbf{e}_z = \sum_\beta \mathsf{R}^{(\alpha\beta)} \cdot \mathbf{V}_t^{(\beta)}, \tag{2}$$

where $\tilde{St}$ is the effective Stokes number which represent the inertial effect of particles, $\mathbf{U}^{(\alpha)}$ is the velocity of particle α, $\mathbf{V}_t$ denotes the instantaneous terminal velocity depending on the configuration, $-\mathbf{e}_z$ is the unit vector directed to the gravity and R is the resistance matrix which is constructed by the procedure of the Stokesian dynamics [3] with periodic boundary condition [4].

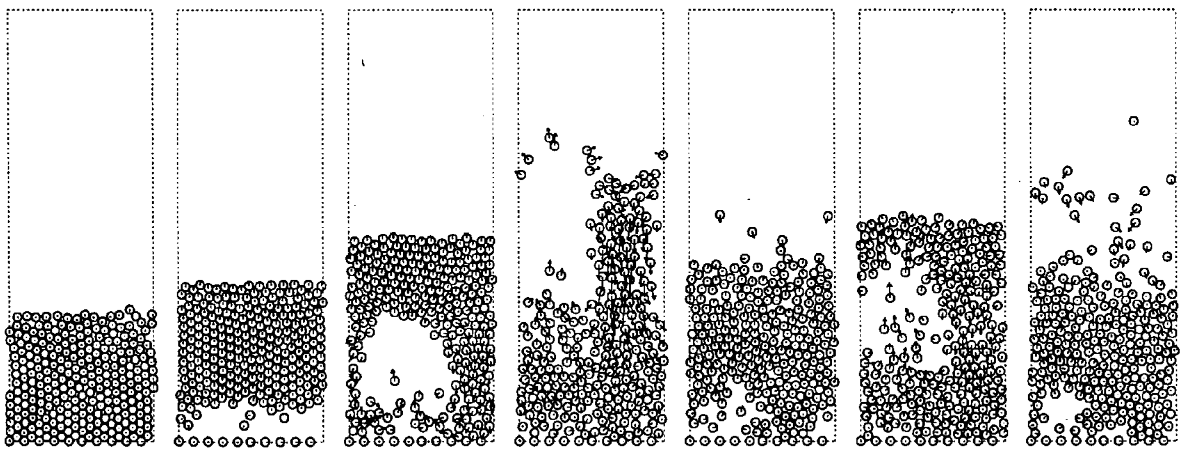

FIG. 1. Sequence of the simulation of a fluidized bed.

In the simulations of fluidized beds, realistic bubbles and slugs for gas-fluidized beds and channel flows for liquid-fluidized beds are observed (Fig. 1). It is found that the convective

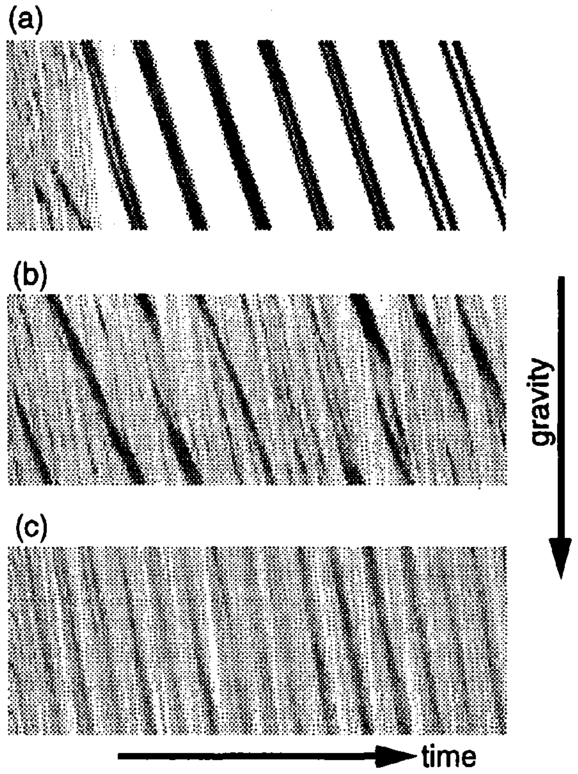

FIG. 2. Spatiotemporal patterns of density with (a) $St' = 0$,(b) $St' = 10$ and (c) $St' = 100$. Dark regions correspond to high densities.

motion of particles is important for the bubbling phase and there is no convection in the slugging phase. In the particle velocities non-Gaussian distributions are found and the relation between the deviation from Gaussian and the local density of particles is suggested.

In the simulations of pipe flows (Fig. 2), density waves are observed over the wide range of the Stokes number. The formation of density waves can be understood by the density dependence of sedimentation rage [5]. Power spectra of density waves in the simulations with non-zero Stokes number show $1/f^{\alpha}$ power law which is similar to that in experiments. This $1/f^{\alpha}$ law may be understood by internal motion of particles in a cluster, which is analogous to that in polymer systems [6].

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